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DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
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CURVES FOR THE CLASSIFICATION OF COAL

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BY

J. F. BARKLEY AND L. R. BURDICK

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INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

CURVES FOR THE CLASSIFICATION OF COAL[1]

By J. F. Barkley[2] and L. R. Burdick[3]

Under the procedure of the American Standards Association, with the American Society for Testing Materials as sponsor, the Sectional Committee on Classification of Coals has arrived at the classification of coals by rank as shown in Table 1[4].

The standard explains the term "agglomerating" used for classification under physical properties, as follows:

> Agglomerating Index. - Coals which in the volatile-matter determination produce either an agglomerate button that will support a 500-g weight without pulverizing, or a button showing swelling or cell structure, shall be considered agglomerating from the standpoint of classification.***. Pending the adoption of a method by the American Society for Testing Materials, the coke-button grading test[5] afforded by the examination of the residue in the platinum crucible incident to the volatile matter determination, shall be used.

The volatile-matter determination referred to is the ordinary laboratory determination made for the usual proximate analysis. The agglomerating property of a coal is related to its caking or coking characteristics. If a coal did not give a button in the test that would classify it as agglomerating, it would not be expected that the coal would cake or coke much in use.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgement is used: "Reprinted from U. S. Bureau of Mines Information Circular 6933."

2/ Supervising engineer, Fuel Economy Service, U. S. Bureau of Mines.

3/ Associate engineer, Fuel Economy Service, U. S. Bureau of Mines.

4/ Proceedings, American Society for Testing Materials, vol. 35, part I, pp. 847-853 (1935), and revision: 1936 Report of Sectional Committee on Classification of Coals, Proceedings A.S.T.M., Part I (1936).

5/ Gilmore, R. E., Connell, G. P., and Nicolls, J. H. H., Agglomerating and Agglutinating Tests for Classifying Weakly Caking Coals: Trans. Am. Inst. Min. and Met. Eng., Coal Division, vol. 108, 1934, p. 255.

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TABLE 1. - Classification of coals by rank

Legend: F. C. = Fixed carbon. V.M. = Volatile matter B.t.u. = British thermal units.

Class	Group	Limits of fixed carbon or B.t.u., mineral-matter-free basis	Requisite physical properties
I. Anthracitic	1. Meta-anthracite	Dry F.C., 98 percent or more (dry V.M., 2 percent or less)	
	2. Anthracite	Dry F.C., 92 percent or more and less than 98 percent (dry V.M., 8 percent or less and more than 2 percent).	
	3. Semianthracite	Dry F.C., 86 percent or more and less than 92 percent (dry V.M., 14 percent or less and more than 8 percent)	Nonagglomerating[1]
II. Bituminous[2]	1. Low-volatile bituminous coal	Dry F.C., 78 percent or more and less than 86 percent (dry V.M., 22 percent or less and more than 14 percent).	
	2. Medium-volatile bituminous coal	Dry F.C., 69 percent or more and less than 78 percent (dry V.M., 31 percent or less and more than 22 percent).	
	3. High-volatile A bituminous coal	Dry F.C., less than 69 percent (dry V.M., more than 31 percent); and moist[3] B.t.u., 14,000[4] or more.	
	4. High-volatile B bituminous coal	Moist[3] B.t.u., 13,000 or more and less than 14,000[4]	
	5. High-volatile C bituminous coal	Moist B.t.u., 11,000 or more and less than 13,000[4]	Either agglomerating or nonweathering[5]
III. Subbituminous	1. Subbituminous A coal	Moist B.t.u., 11,000 or more and less than 13,000[4]	Both weathering and nonagglomerating
	2. Subbituminous B coal	Moist B.t.u., 9,500 or more and less than 11,000[4]	
	3. Subbituminous C coal	Moist B.t.u., 8,300 or more and less than 9,500[4]	
IV. Lignitic	1. Lignite	Moist B.t.u., less than 8,300.	Consolidated
	2. Brown coal	Moist B.t.u., less than 8,300.	Unconsolidated

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FOOTNOTES FOR TABLE 1

1/ If agglomerating, classify in low-volatile group of the bituminous class.

2/ Pending the report of the Subcommittee on Origin and Composition and Methods of Analysis, it is recognized that there may be non-caking varieties in each group of the bituminous class.

3/ Moist B.t.u. refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

4/ Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of B.t.u.

5/ There are three varieties of coal in the high-volatile C bituminous coal group, namely, variety 1, agglomerating and nonweathering; variety 2, agglomerating and weathering; variety 3, nonagglomerating and nonweathering.

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The term "weathering" is explained:

> Weathering Index. - Coals showing average weathering indices of less than 5 percent shall be considered nonweathering; coals showing average weathering indices of 5 percent or more shall be considered weathering from the standpoint of classification.***. Pending the adoption of a method by the American Society for Testing Materials, the weathering or slacking characteristics of coals shall be determined by the United States Bureau of Mines method[6] modified with respect to the selection of a standard humidity. Briefly, the test consists of air-drying 500 to 1,000 g of approximately 1- to 1 1/2-inch lumps at a temperature of 30° to 35° C. and a humidity of 30 to 35 percent for a period of 24 hours, and then immersing the lumps in water for 1 hour; the water then being drained off and the sample again air-dried for 24 hours. The amount of disintegration is determined by sieving on an 8-inch wire-mesh sieve with 0.263-inch square openings, and weighing the quantity of coal passing (undersize) and that retained on (oversize) the sieve. The percentage of coal passing the sieve (undersize), after deducting a blank sieving test, is the weathering or slacking index of the coal.

This index is related to the amount of weathering or slacking that a coal undergoes, for example, in storage. If a coal had a weathering inde of more than 5 percent, it would not be expected to store well.

The classification covers essentially all coals. It is planned to exclude a few coals that come within the limits of fixed carbon or B.t.u. of the high-volatile bituminous and subbituminous ranks that have unusual physical and chemical characteristics. Such coals do not occur abundantl and have either very low, dry, mineral-matter-free fixed carbon or very high, moist, mineral-matter-free B.t.u. The exact values have not yet bc determined but probably will be below about 48 percent dry, mineral-matte free fixed carbon and above about 15,500 moist, mineral-matter-free B.t.u

As shown in the third column of table 1, the classification is base on the dry fixed carbon and the moist B.t.u., both on a mineral-matter-f basis. This is not the same as an ash-free basis. The ash, as reported in the usual coal analysis, is not the true mineral matter as found in the coal, but is the residue left after certain ignition or burning carried out as part of the laboratory procedure. Such burning causes chang in the mineral matter. Values for dry, mineral-matter-free fixed carbon and moist, mineral-matter-free B.t.u. may be obtained by calculation fro the usual coal analysis. Such calculations are based on certain chemical assumptions as to what happens to the mineral matter or non-coal substan when the laboratory "ash" analysis is made. The standard states:

6/ Fieldner, A. C., Selvig, W. A., and Frederic, W. H., Accelerated Lab tory Test for Determination of Slacking Characteristics of Coal: of Investigations 3055, Bureau of Mines, 1930, 24 pp.

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For classification of coal according to rank, fixed carbon and B.t.u. shall be calculated to the mineral-matter-free basis in accordance with either the Parr[7] formulas (1), (2), and (3) or the approximation formulas (4), (5), and (6) given below. In case of litigation the appropriate Parr formula shall be used.

Calculation from "moist" basis:

Parr formulas:

$$\text{Dry, Mm-free F.C.} = \frac{\text{F.C.} - 0.15\text{S}}{100 - (\text{M} + 1.08\,\text{A} + 0.55\text{S})} \times 100 \quad \ldots\ldots\ldots (1)$$

$$\text{Dry, Mm-free V.M.} = 100 - \text{Dry, Mm-free F.C.} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$\text{Moist, Mm-free B.t.u.} = \frac{\text{B.t.u.} - 50\text{S}}{100 - (1.08\,\text{A} + 0.55\text{S})} \times 100 \quad \ldots\ldots\ldots (3)$$

Note. - The above formula for fixed carbon is derived from the Parr formula for volatile matter.

Approximation formulas:

$$\text{Dry, Mm-free F.C.} = \frac{\text{F.C.}}{100 - (\text{M} + 1.1\,\text{A} + 0.1\text{S})} \times 100 \quad \ldots\ldots\ldots\ldots (4)$$

$$\text{Dry, Mm-free V.M.} = 100 - \text{Dry, Mm-free F.C.} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

$$\text{Moist, Mm-free B.t.u.} = \frac{\text{B.t.u.}}{100 - (1.1\,\text{A} + 0.1\text{S})} \times 100 \quad \ldots\ldots\ldots\ldots (6)$$

where:

Mm	=	mineral matter;
B.t.u.	=	British thermal units;
F.C.	=	percentage of fixed carbon;
V.M.	=	percentage of volatile matter;
M	=	percentage of moisture;
A	=	percentage of ash;
S	=	percentage of sulfur.

Moist refers to coal containing its natural bed moisture, but not including visible water on the surface of the coal.

The B.t.u. and all percentage values are on a moist basis. The percentage of fixed carbon + volatile matter + moisture + ash = 100. This is similar to the usual "as received" basis, except that the amount of moisture must be as defined in the standard. As shown in the table, coals higher in rank than bituminous high volatile are classified according to the dry, mineral-matter-free fixed carbon, the moisture, either as natural bed moisture or in any other amount, not affecting the classification. For such coals, "as received" analyses would serve to determine the rank. For the remaining lower-

[7] Parr, S. W., The Classification of Coal: University of Illinois Eng. Exper. Sta. Bull. 180, 1928.

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rank coals the moist, mineral-matter-free B.t.u. affects the classification, the analysis must be on the moist basis as defined. To obtain the proper m the standard goes into detail as to proper methods of sampling, both for be samples and for tipple or shipment samples.

In classifying a coal bed, samples from outcrops, from weathered, or f oxidized coal are not to be used. Coals that contain more than 1 percent c dioxide occurring as carbonates are given special laboratory treatment in a riving at the analyses.

The above formulas may also be expressed on the dry basis, as follows:

Parr formulas:

$$\text{Dry, Mm-free F. C.} = \frac{\text{F.C.} - 0.15S}{100 - (1.08\,A + 0.55S)} \times 100 \quad \text{..... (A)}$$

$$\text{Dry, Mm-free V.M.} = 100 - \text{Dry, Mm-free F.C.} \quad \text{..... (B)}$$

$$\text{Moist, Mm-free B.t.u.} = \frac{\text{B.t.u.} - 50S}{\frac{10,000}{100-M} - (1.08\,A + 0.55S)} \times 100 \quad \text{..... (C)}$$

Approximation formulas:

$$\text{Dry, Mm-free F.C.} = \frac{\text{F.C.}}{100 - (1.1\,A + 0.1S)} \times 100 \quad \text{..... (D)}$$

$$\text{Dry, Mm-free V.M.} = 100 - \text{Dry, Mm-free F.C.} \quad \text{..... (E)}$$

$$\text{Moist, Mm-free B.t.u.} = \frac{\text{B.t.u.}}{\frac{10,000}{100-M} - (1.1\,A + 0.1S)} \times 100 \quad \text{..... (F)}$$

In these equations, the B.t.u. and all percentage values, except the moisture, used on the right side of the equations are on the dry basis. percentage of fixed carbon + volatile matter + ash = 100. The moisture p age is on the moist basis, as is customary when the proximate analysis of coal is given on the dry basis.

Values obtained from the approximation formulas differ from those ob from the Parr formulas in amounts depending upon analyses of the coal. usual differences run from 0 percent to about 0.8 percent in F.C. and fro to about 85 in B.t.u.

The accompanying curves (figs. 1-6) can be used to solve the formula quickly. They can also be used as a protecting check when the formulas a solved by calculations. With reasonable care, the maximum error in any d determination, when the curves on the moist basis are used, should not be than 0.5 percent when percentages are being determined and not more than B.t.u. when B.t.u. are being determined; when the curves on the dry basis used, the maximum error should not be more than 0.2 percent and 75 B.t.u. When the result comes very close to a division line in the classificatio coal, as, for example, 78 percent F.C., it would be desirable to solve th equation by calculation rather than curves. Many coals, however, fall fa enough away from the classification division lines to make it unnecessary use calculations to determine classification.

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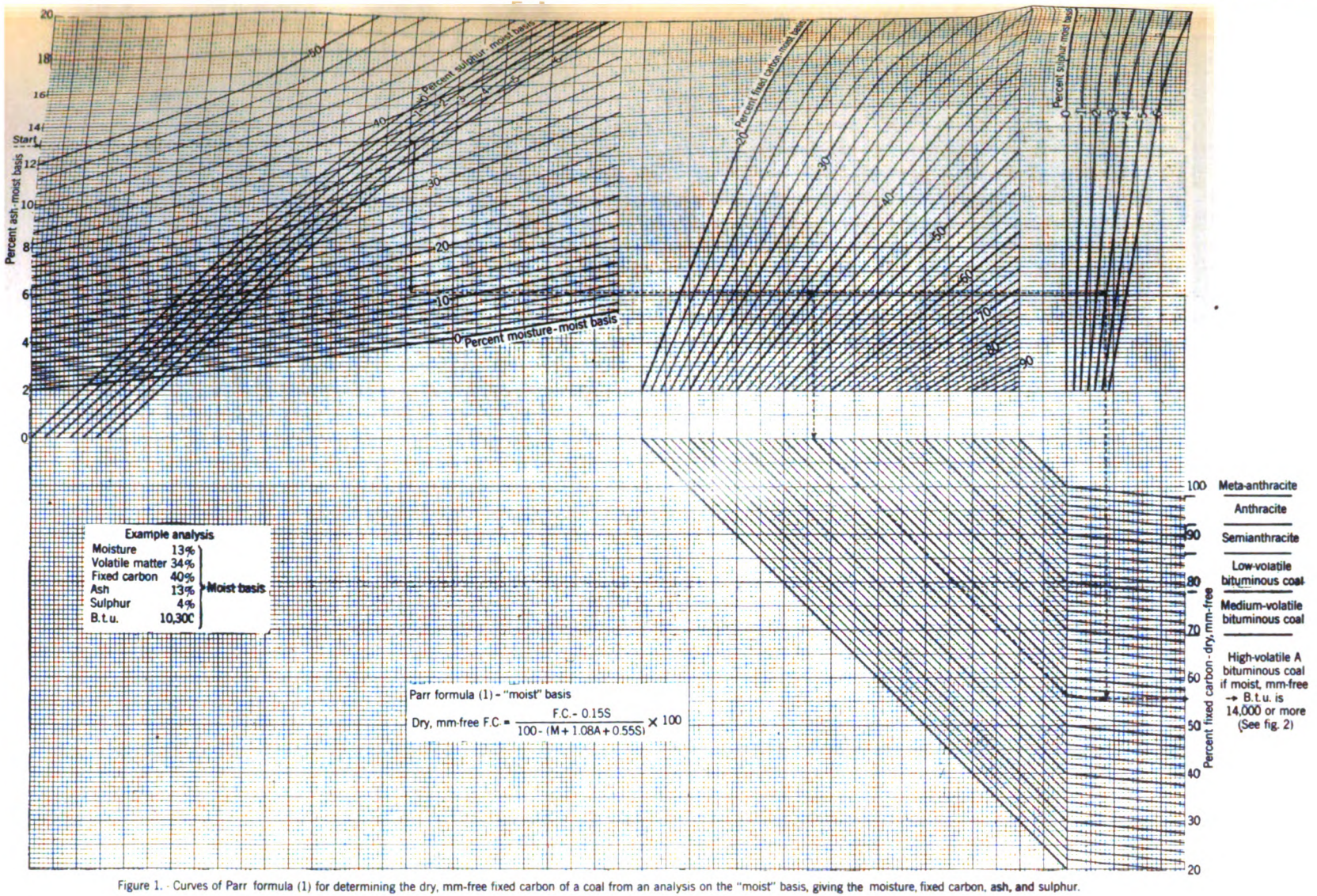
Percent ash - moist basis
Start
Percent sulphur - moist basis
Percent moisture - moist basis
Percent fixed carbon - mm-free basis
Percent sulphur - moist basis
Example analysis
Moisture 13%
Volatile matter 34%
Fixed carbon 40%
Ash 13%
Sulphur 4%
B.t.u. 10,300
Moist basis
Parr formula (1) - "moist" basis
Dry, mm-free F.C. = F.C. - 0.15S / 100 - (M + 1.08A + 0.55S) × 100
Percent fixed carbon - dry, mm-free
Meta-anthracite
Anthracite
Semianthracite
Low-volatile bituminous coal
Medium-volatile bituminous coal
High-volatile A bituminous coal if moist, mm-free → B.t.u. is 14,000 or more (See fig. 2)

Figure 1. - Curves of Parr formula (1) for determining the dry, mm-free fixed carbon of a coal from an analysis on the "moist" basis, giving the moisture, fixed carbon, ash, and sulphur.

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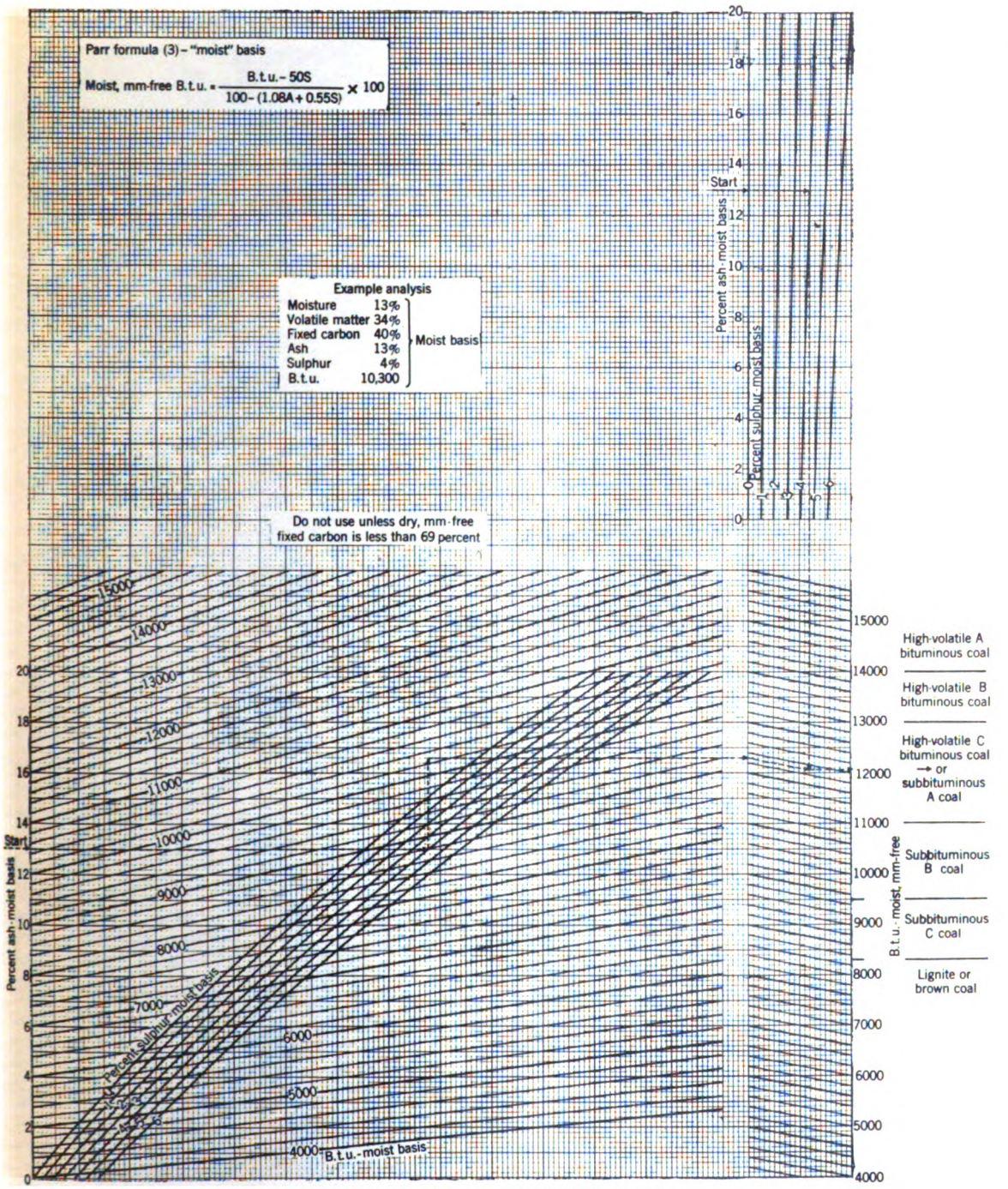
Parr formula (3) – "moist" basis
Moist, mm-free B.t.u. = (B.t.u. – 50S) / (100 – (1.08A + 0.55S)) × 100
Example analysis
Moisture 13%
Volatile matter 34%
Fixed carbon 40%
Ash 13%
Sulphur 4%
B.t.u. 10,300
Moist basis
Do not use unless dry, mm-free fixed carbon is less than 69 percent
Start
Percent ash-moist basis
Percent sulphur-moist basis
B.t.u.-moist basis
B.t.u. moist, mm-free
High-volatile A bituminous coal
High-volatile B bituminous coal
High-volatile C bituminous coal → or subbituminous A coal
Subbituminous B coal
Subbituminous C coal
Lignite or brown coal

Figure 2. · Curves of Parr formula (3) for determining the moist, mm-free B.t.u. of a coal from an analysis on the "moist" basis giving the ash, sulphur, and B.t.u.

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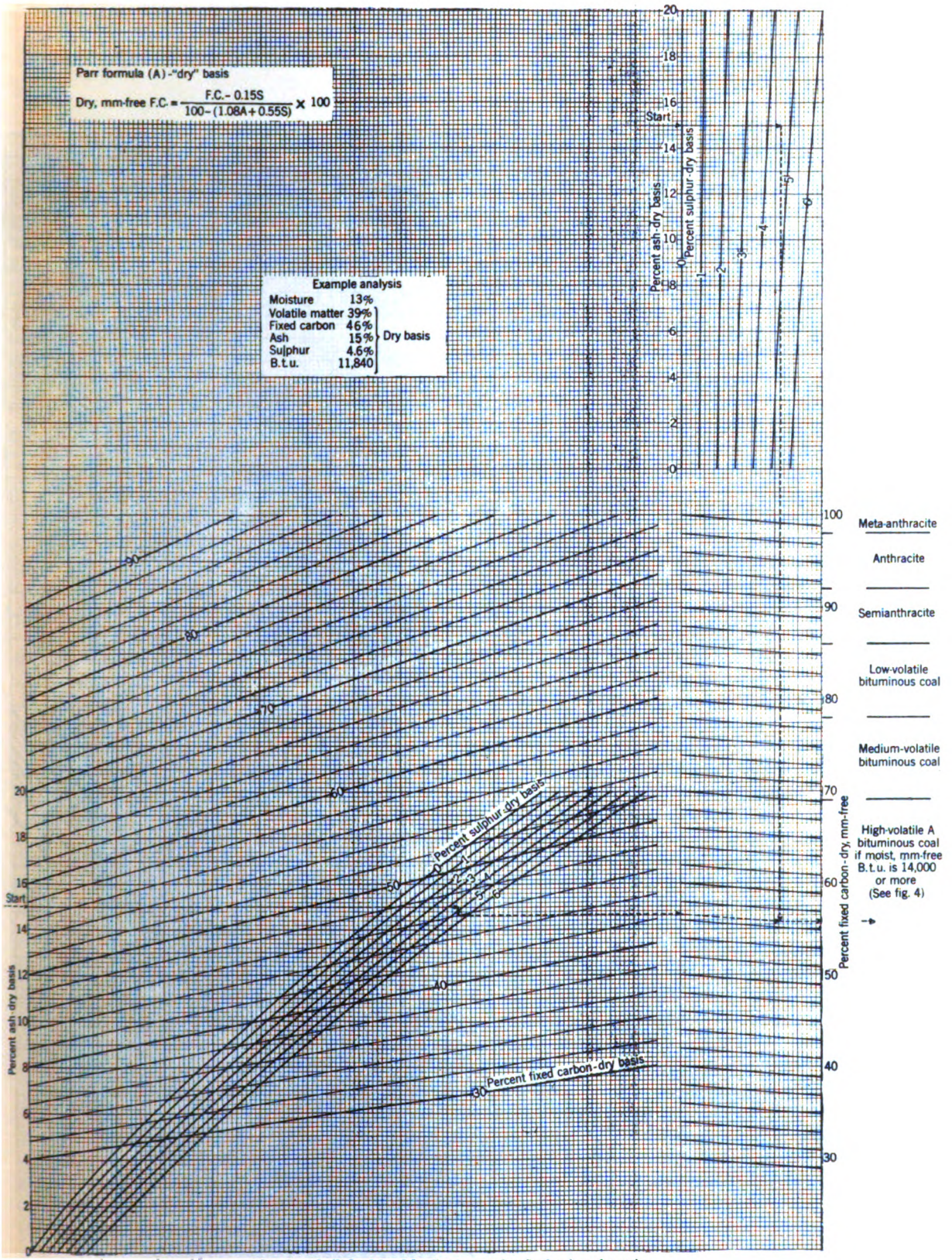

Figure 3. - Curves of Parr formula (A) for determining the dry, mm-free fixed carbon of a coal from an analysis on the "dry" basis giving the fixed carbon, ash, and sulphur.

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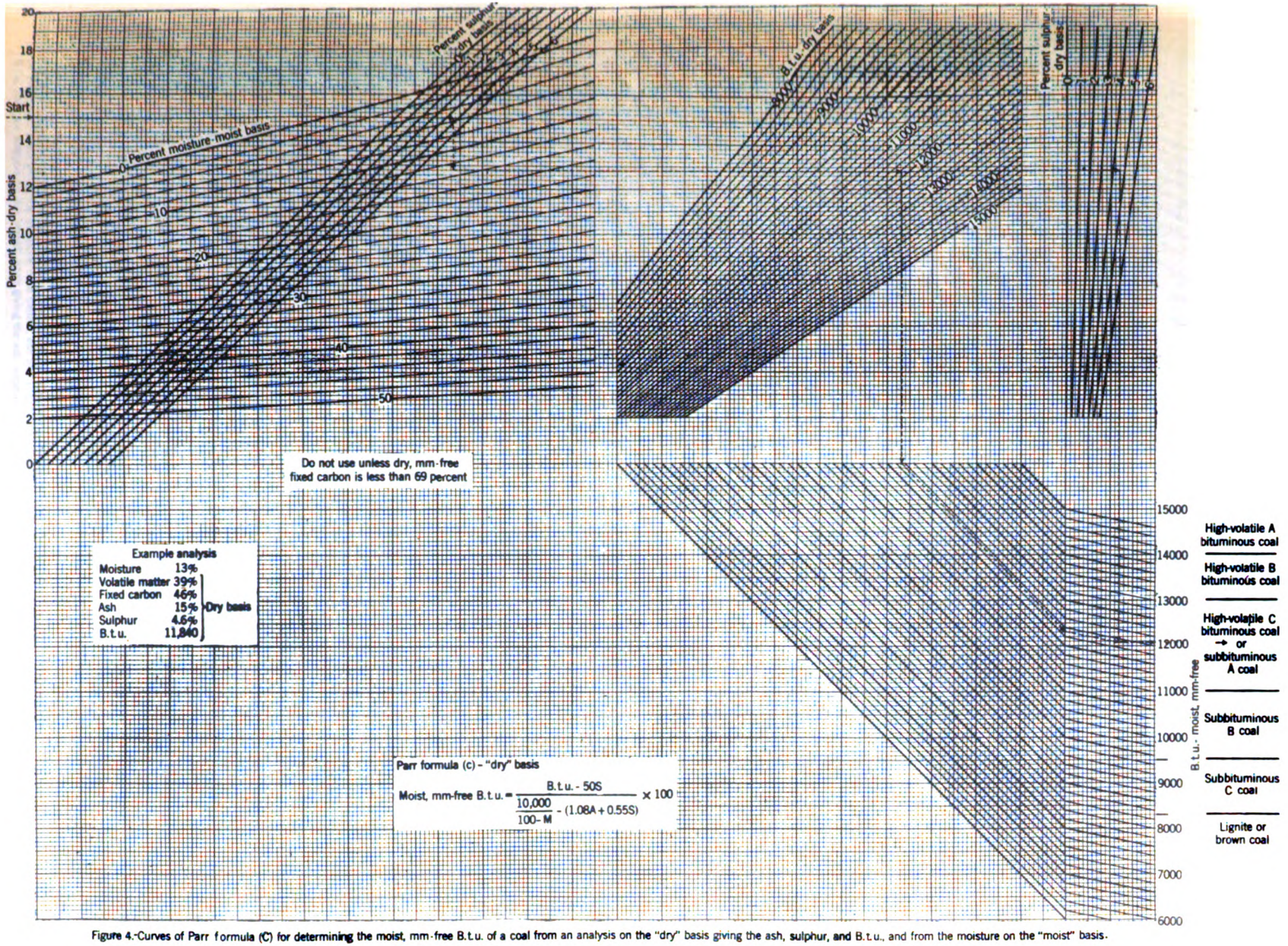
Percent ash-dry basis
Start
Percent moisture-moist basis
Percent sulphur-dry basis
B.t.u.-dry basis
Do not use unless dry, mm-free fixed carbon is less than 69 percent
Example analysis
Moisture 13%
Volatile matter 39%
Fixed carbon 46%
Ash 15%
Sulphur 4.6%
B.t.u. 11,840
Dry basis
Parr formula (c) - "dry" basis
Moist, mm-free B.t.u. = (B.t.u. - 50S) / (10,000/(100-M) - (1.08A + 0.55S)) × 100
B.t.u.-moist, mm-free
High-volatile A bituminous coal
High-volatile B bituminous coal
High-volatile C bituminous coal → or subbituminous A coal
Subbituminous B coal
Subbituminous C coal
Lignite or brown coal

Figure 4.-Curves of Parr formula (C) for determining the moist, mm-free B.t.u. of a coal from an analysis on the "dry" basis giving the ash, sulphur, and B.t.u., and from the moisture on the "moist" basis.

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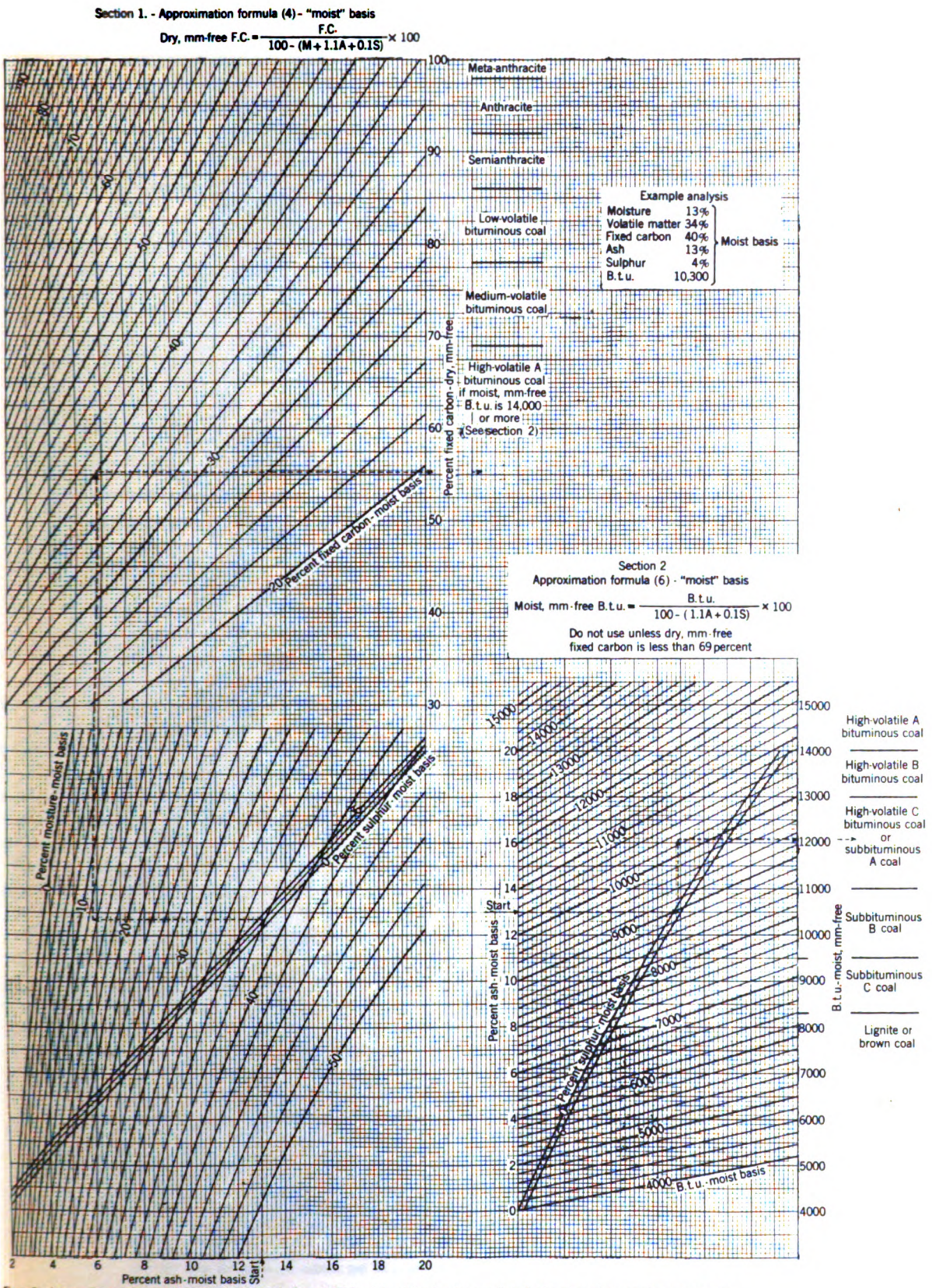
Section 1. - Approximation formula (4) - "moist" basis
Dry, mm-free F.C. = F.C. / 100 - (M + 1.1A + 0.1S) × 100
Meta-anthracite
Anthracite
Semianthracite
Low-volatile bituminous coal
Medium-volatile bituminous coal
High-volatile A bituminous coal if moist, mm-free B.t.u. is 14,000 or more (See section 2)
Example analysis
Moisture 13%
Volatile matter 34%
Fixed carbon 40%
Ash 13%
Sulphur 4%
B.t.u. 10,300
Moist basis
Percent fixed carbon, dry, mm-free
Percent fixed carbon - moist basis
Section 2
Approximation formula (6) - "moist" basis
Moist, mm-free B.t.u. = B.t.u. / 100 - (1.1A + 0.1S) × 100
Do not use unless dry, mm-free fixed carbon is less than 69 percent
Percent moisture - moist basis
Percent sulphur - moist basis
Percent ash - moist basis
Start
B.t.u. - moist basis
B.t.u. - moist, mm-free
High-volatile A bituminous coal
High-volatile B bituminous coal
High-volatile C bituminous coal or subbituminous A coal
Subbituminous B coal
Subbituminous C coal
Lignite or brown coal

Figure 5. - Curves of approximation formulas. Section 1, formula (4) for determining the dry, mm-free fixed carbon of a coal from an analysis on the "moist" basis giving the moisture, fixed carbon, ash and sulphur. Section 2, formula (6) for determining the moist, mm-free B.t.u. from an analysis on the "moist" basis giving the ash, sulphur, and B.t.u.

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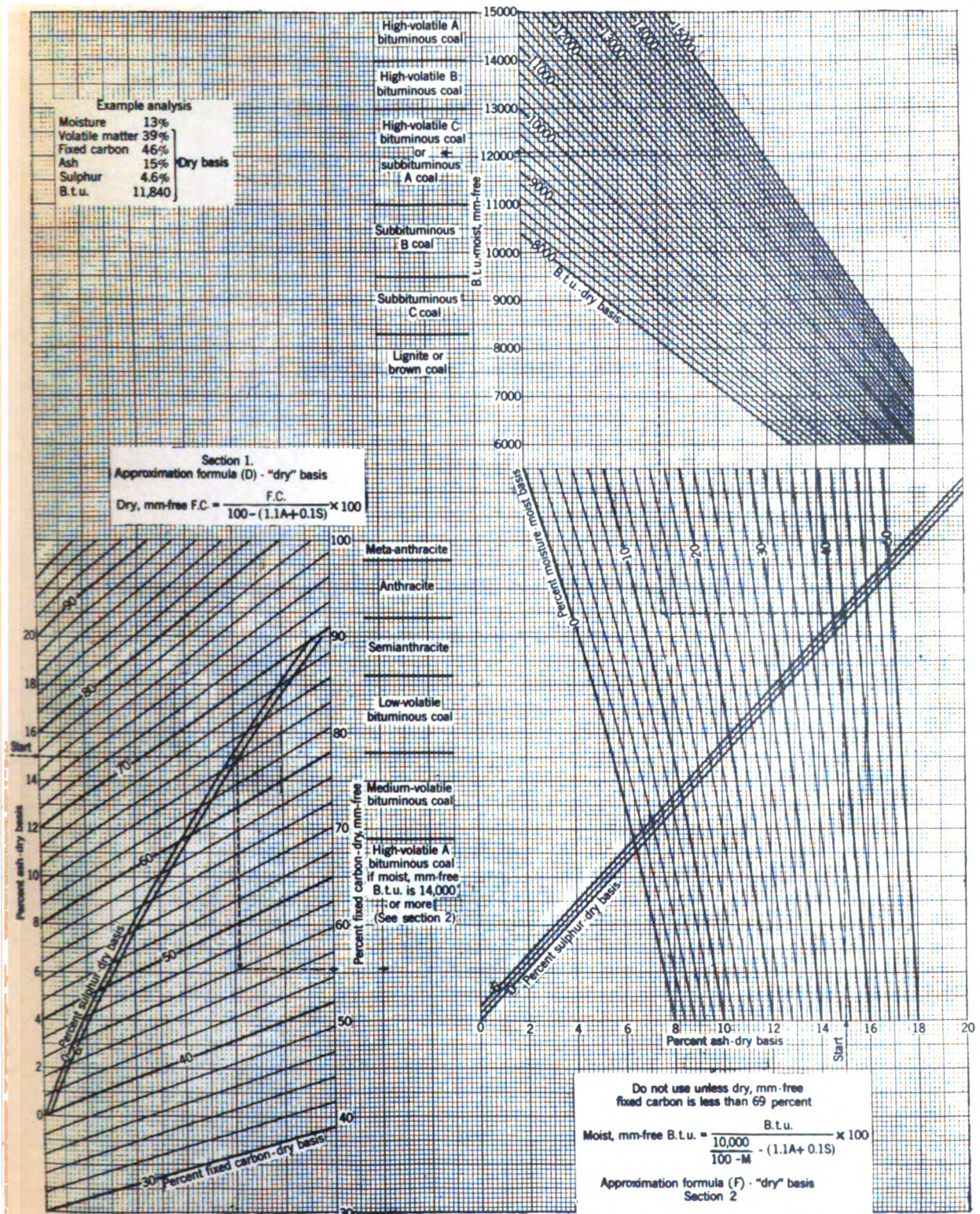

Figure 6. - Curves of approximation formulas. Section 1, formula (D) for determining th. dry, mm-free fixed carbon of a coal from an analysis on the "dry" basis giving the fixed carbon, ash and sulphur. Section 2, formula (F) for determining the moist, mm-free B.t.u. from an analysis on the "dry" basis giving the ash, sulphur, and B.t.u., and from the moisture on the "moist" basis.

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